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Introduction

Since the original Cognitive Radio (CR) concept had emerged [1], [2], the opportunistic usage of selected frequency bands has become one of the most promising application scenarios from the perspective of a near- to mid-term broad market deployment [3], [4]. Driven by the prospect of a hugely increased overall spectral efficiency through the opportunistic exploitation of otherwise unused frequency bands and the favorable propagation conditions in some of the considered bands (such as the TV white spaces at 470-790 MHz [5]), a series of large-scale research projects have studied the practical feasibility of such system concepts. Some well-known examples include the European funded projects IST-E2R, IST-E2R II [6], ICT-E3 [7], etc. Moreover, the Federal Communications Commission (FCC) in the USA has defined a set of rules for deploying Cognitive Radio Systems (CRS) [8], which are currently further considered in an European regulatory framework by CEPT (European Conference of Postal and Telecommunications Administrations) in the SE43 group [9]. *The key approach proposed by US and European regulators for ensuring the protection of frequency bands used by primary users consists in the set-up of a database, containing information related to the spectrum usage of primary users, in combination with terminal-based spectrum sensing techniques*.

The general opportunistic spectrum usage approach has been broadly studied and published in the scientific literature. Recent publications, however, consider specific applications which differ from the generic opportunistic terminal approach. In this framework, [10] has recently introduced the concept of opportunistic relay. The authors outline the advantages and possible gains of using opportunistic relay nodes in the context of a cellular communication network. More specifically, if TV White Space frequencies in the range of 470 MHz to 790 MHz are available, they can be exploited with the following potential advantages: i) lighter infrastructure deployment, ii) increased spectral efficiency through less propagation losses and iii) increased spectral efficiency through extended macro diversity. This paper further illustrates how the approach in [10] is aligned to the regulatory requirements. In particular, the paper focuses on problems related to the detection of white spaces, by jointly exploiting information available from central & distributed databases and from distributed spectrum sensing algorithms at the relay nodes.

The reminder of this paper is organized as follows. The next section introduces the overall system concept, enriching the proposal in [10] with databases providing spectrum usage information. Then, the interactions between relay nodes and databases are considered. Finally, conclusion is given.

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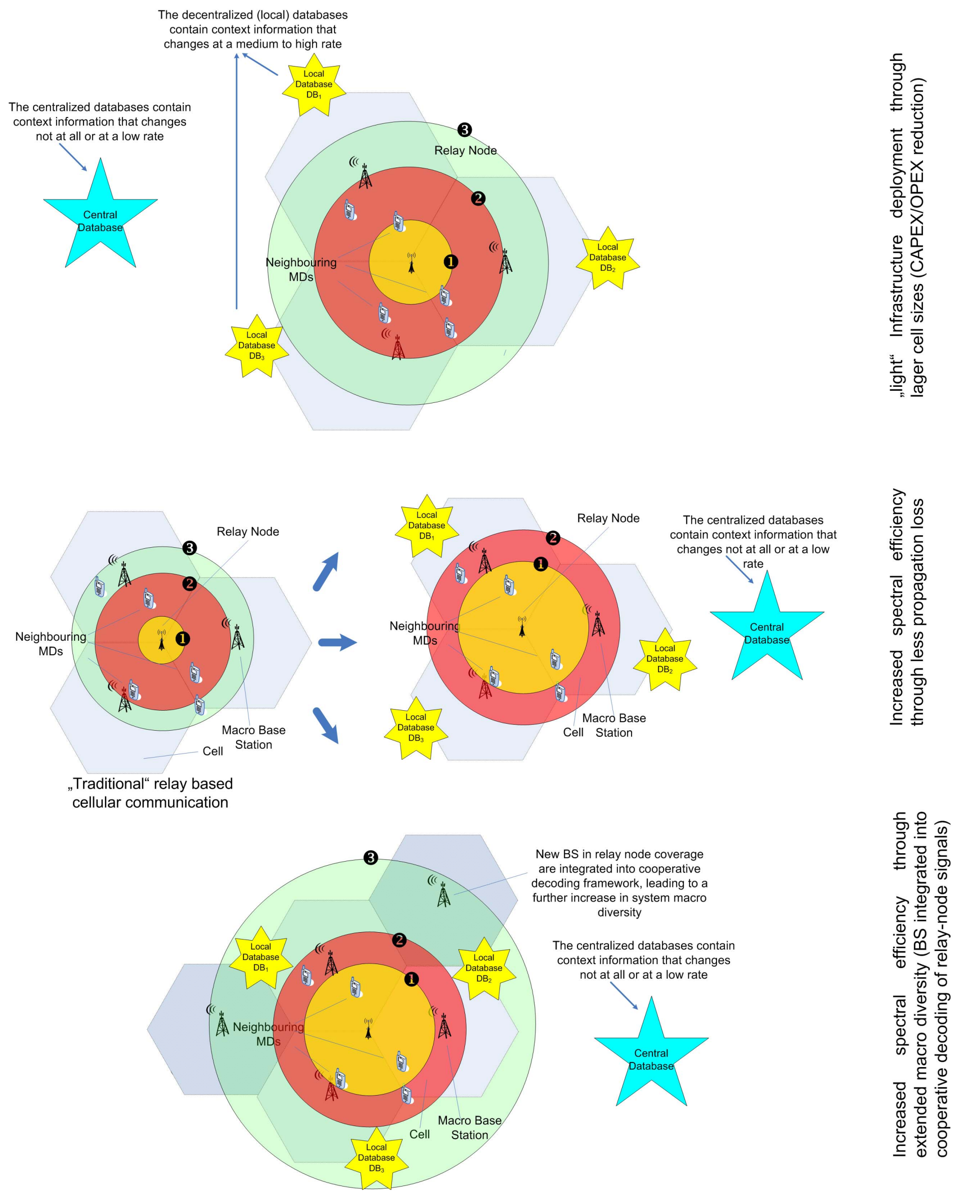

Figure 1: TV White Space relaying framework including databases

A TV White Space Relaying Framework

In Fig. 1, we have summarized the benefits that can potentially be achieved by our proposed TV White Space relaying framework. The ideas in Fig. 1 extend the framework introduced in [10] by envisaging the synergic interaction of distributed spectrum sensing algorithms and central & distributed databases, which have geographic information about the spectrum potentially available for opportunistic communications, to identify spectrum holes in the TV band.

In particular, Fig. 1 depicts a Mobile Device (MD) which wants to send data to a macro Base Station (BS), and vice versa. To reduce the transmission power, increase the link quality, or improve the system diversity, the MD might opportunistically exploit a relay node, which is willing to forward data to the macro BS of interest. Throughout this paper, we assume that the communications with the relay node (both the MD-to-relay and relay-to-BS, and vice versa) occur over the TV frequency band, when white spaces are available and are correctly detected in this band.

The fundamental advantage of exploiting the white spaces in the TV band for opportunistic relying resides in the reduced propagation losses experienced by the wireless signals in the 470-790 MHz band, when compared to conventional higher frequency bands used for cellular networks, e.g., the 2 GHz band. This introduces three main potential benefits:

1. *Lighter infrastructure deployment through larger cell sizes*. If we assume that the probability of a white space in the TV band being available for opportunistic relaying is high, the lower propagation losses experienced by the wireless signals over the TV band allow us to increase the cell size of the cellular system. This results in a less dense infrastructure deployment of macro BSs, which reduces CAPEX and OPEX of cellular operators.
2. *Increased spectral efficiency through reduced propagation loss*. Instead of increasing the cell size while keeping the same spectral efficiency, the reduced propagation losses over the TV band can be exploited to switch the link parameters of the communication protocol to a less robust setting, thus yielding a higher spectral efficiency and a higher data throughput.
3. *Increased spectral efficiency through extended macro diversity*. Instead of increasing the cell size or modifying the modulation and coding parameters at the physical layer, we can consider a third option where the cellular network in Fig. 1 opportunistically exploits the relay node by keeping all link parameters as in a non-relay-based deployment. In such a case, due to the reduced propagation losses over the TV band, the signal emitted by the relay can be overheard by more distant macro BS and exploited in a cooperative setting to get some macro-diversity gains. This allows the system to improve the performance via cooperative diversity protocols.

Interaction of Terminals with Databases

As explained in [10], there are several advantages in the operation of relay nodes in the TV White Spaces. The main benefit lies in a greater spectral efficiency of the overall system. In this context, the key issue to solve is the design of an efficient decision making process that aims at estimating whether the TV White Spaces are actually available for opportunistic operation (see, e.g., [11] and references therein). According to the constraints and recommendations imposed by the regulatory framework [8], [9], in this paper we propose that this decision-making process is built upon mutual interactions among the three entities as follows:

- A **central database**, which is typically deployed for a large geographic area, such as a country. Mainly, it contains rough information about the availability of primary systems. In general, the central database is required to have only long-term statistical data.
- A **distributed database**, which complements the central database above, is typically deployed for geographic areas in which more detailed information is required for the relay-centric decision-making process. In particular, in dense urban areas a large deployment of distributed databases is expected, since, because of the highly dynamic environment, they need to quickly update their stored information. For example, a distributed database could exploit PMSE (Program Making and Special Events) devices, such as wireless microphones, to update information about the available spectrum. In general, the distributed database is required to have only mid- to short-term statistical data.
- In addition to the central and distributed databases, (distributed) **Spectrum Sensing** algorithms in the relay nodes might be very helpful for several reasons. i) They are useful for real-time updates about the availability of radio resources. ii) They are useful to detect the presence of other (opportunistic/cognitive) radio devices using the available spectrum for opportunistic access. Accordingly, they are of great importance to avoid any interference

with co-located opportunistic devices. iii) They are instrumental for updating the spectrum occupancy information available in the central and distributed databases.

We envisage that the synergic operation of central databases, distributed databases, and distributed spectrum sensing algorithms can ensure a more efficient exploitation of TV White Spaces for opportunistic communications and secondary spectrum access.

Conclusion

In this paper, we have proposed the combination of a centralized & decentralized database and distributed spectrum sensing method for secondary spectrum access. The potential benefits of the proposed solution in a cellular scenario exploiting the TV White Space for opportunistic spectrum access have been outlined.

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